

Influence of Electrodes Characteristics on The Performance of a Microbial Fuel Cell

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Abstract

A single chamber microbial fuel cell is designed incorporating microorganism as catalyst with *Escherichia coli*, *Staphylococcus*, *Klebsilla* bacteria as an electrolyte at pH =7 and an operating temperature of 30 C⁰ in batch mode. The electrodes are made of three different types of materials, namely; aluminum, copper and zinc. Each material is configured at three different shape (circle, rectangle and square) in three different cross sectional areas of (3.14,7.065 and 12.56cm²). The distance between anode and cathode is fixed at different values of 0.5,1,2,4 and 6cm. Results indicate that electrodes of circular shape show the best performance among other shapes investigated in this study, however the area of the anode is found to affect the cell performance more than its shape. Using zinc as an anode material and copper as a cathode in circular shape with cross sectional area of 12.56 cm² and a 2 cm distance between them output the best performance in comparison to other combinations investigated in this study.

Key Words: Microbial Fuel Cell, Electrode, Performance, Microorganism.

الخلاصة

خلايا الوقود الميكروبية هي نوع من خلايا الوقود المعروفة تعمل على تحويل التفاعلات الكيميائية الى طاقة كهربائية باستخدام الكائنات الدقيقة كمحفز . البكتريا المستخدمة في هذا العمل هي الاشريكية القولونية (*E.coli*), بكتريا (*Staphylococcus* bacteria) وبكتريا (*Klebsilla*) في وسط درجة حرارته 30مئويه ودالة الحموضة=7 بطريقة الوجبة الواحدة . الاقطاب اختبرت من ثلاث مواد مختلفة هي الالمنيوم , النحاس والخرصين . كل مادة شكلت الى ثلاث اشكال مختلفة هي (الدائرة, المستطيل والمربع) كل شكل صمم بثلاث مساحات مختلفة المقطع العرضي هي (3.14, 7.065, 12.56) cm والمسافة بين الانود والكاثود عند خمس مسافات مختلفة هي (0.5, 1, 2, 4, 6 cm) . المحصلة تبين بأن الاقطاب للشكل الدائري هي الافضل بالأداء بالمقارنة مع الاشكال الاخرى المدروسة, كذلك مساحة الانود وجدة بأنها تؤثر على الاداء الخلية اكثر من شكلها . باستخدام مادة الخارصين كاثود والنحاس ككاثود للشكل الدائري لمساحة مقطع عرضي (12.56cm²) ومسافه (2cm) بين الانود والكاثود هي عندها تعمل الخلية بأفضل اداء بالمقارنة مع المتغيرات الاخرى للاقطاب .

الكلمات المفتاحية : خلية الوقود الميكروبية - الأقطاب - الأداء - الجراثيم

1. Introduction

Fuel cells are electrochemical devices that convert the intrinsic chemical energy in fuels into electrical energy directly. The fuel cell was first demonstrated by William Grove in 1839 . In a typical fuel cell, fuel is fed continuously to the anode (negative electrode) and an oxidant (often oxygen in air) is fed continuously to the cathode (positive electrode). As such, fuel cells promise power generation at high efficiency and low environmental impact. In addition, because combustion is avoided, fuel cells produce power with minimal pollutants ,(Scott ,2012).

Fuel cells could be broadly categorized into abiotic fuel cells (chemical fuel cells) whose which the fuel cell components do not comprise any biological material and biotic (biological fuel cells) which comprises, living organisms or biological material (such as enzymes or microorganism) .

Biological fuel cells utilize organic substrates (such as sugars and alcohols) and operate at mild temperature environments where biological activity is optimal. While both microorganisms and enzymes catalyze oxidative reactions that takes place at the anode, only enzymes (sometime coupled with inorganic catalysts) are used in the cathode , (Mahadevan ,2014) .

The biotic fuel cell (biological fuel cell) can be divided in two types: microbial' fuel cells and 'enzymatic' fuel cells, depending on the biocatalysts used. Microbial fuel cells (MFCs) use whole living organisms while enzymatic biofuel cells use

isolated and purified enzymes as specific catalysts ,in an enzymatic fuel cell, the oxidation reactions that are catalyzed by enzymes , alternatively ,when the catalyst is an organism , the cell is called as a microbial fuel cell ,(Scott ,2012).

1.1 Microbial fuel cell

A microbial fuel cell (MFC) is a bioreactor that converts chemical energy in the chemical bonds in organic compounds to electrical energy through catalytic reactions of microorganisms under anaerobic conditions.

In this MFC, anaerobic bio catalytic anodes are used to generate electrons and protons. The electrons generated at the anode travel to the cathode via an external circuit (electrical load) and combine with protons that diffuse through the membrane and they are reduced to form water on the cathode electrode in the presence of oxygen. MFCs can be operated by supplying any form of biodegradable organic matter, such as carbohydrates, fatty acids, proteins, and animal or human wastewater. The profound benefit of MFCs is the combination of electricity generation with simultaneous wastewater treatment ,(Rahimnejad ,2015).

The fact that bacteria can oxidize the substrates to produce electricity makes MFCs an ideal solution for wastewater treatment and domestic energy production, (Karmakar ,2010).Anodic chamber consists of organic material and microorganism, cathodic chamber also consist of oxygen and proton ,oxygen serves as an ideal electron acceptor due to its non-toxic effect and it is preferred as oxidizing reagent because it simplifies operation of an MFC due to the fact that Power output of an MFC strongly depends on the concentration level of electron acceptors, (Das,2010). Several parameters have effect on the performance of MFC, namely microbial inoculums, chemical substrates, mass transfer area, absence or existence of proton exchange materials, mechanism of electron transfer to the anode surface ,cell internal and external resistance, solution ionic strength, electrode materials and the electrode spacing, (Cheng ,2006).

1.2 Design of Microbial Fuel Cell

There are basic components of MFCs, which are important in constructions. Electrodes, cell container, wirings and proton exchange membrane have an important role. Proton Exchange membranes also play an important part but they are very costly and they need proper installation procedures for limiting the dangers of clogging and drying. Though higher fuels are preferable but most of the time they are inhibitory to microorganism ,(Shukla ,2004).A typical design of microbial fuel cell can be classified into two types: a) Double chamber MFC. b) Single chamber MFC, They are operated under different conditions to increase the performance power output and reduce the overall cost, (Karmakar ,2010)

1.2.1 Double chamber Microbial Fuel Cell

A typical double chamber MFC has an anodic chamber and a cathodic chamber connected by a PEM, or sometimes by a salt bridge, to allow protons to move across to the cathode while blocking the diffusion of oxygen into the anode. Copper wire can be expected to eventually fail in the system. To avoid wires inside the chambers, the electrodes can be extended outside the chamber and then a regular wire and clip can be placed on the electrode (Karmakar,2010). Inexpensive design is a two chamber MFC built in a traditional “H” shape, consisting usually of two bottles connected by a tube containing a separator which is usually a cation exchange membrane (CEM) such as Nafion or Ultrex or a plain salt bridge ,(Liu ,2004).

1.2.2 Single chamber Microbial Fuel Cell

This design has only one compartment that contains both the anode and the cathode (Karmakar,2010) One compartment MFCs offer simpler designs and cost savings. Due to their complex designs, two-compartment MFCs are difficult to scale-

up even though they can be operated in either batch or continuous mode (Das ,2010). It reduces internal ohmic resistance by avoiding the use of catholyte as a result of combining two chambers and thus increases the power density. Several designs are possible for this system, In the first design used in laboratories, which is employed to demonstrate electricity generation from wastewater, the cathode was placed in the center of a cylinder, so that the anode chamber formed a concentric cylinder around the cathode (Huggins,2013). Another MFC design inspired by the same general idea , but with a rectangular container and without a physical separation is achieved by using glass wool and glass beads. The feed stream is supplied to the bottom of the anode and the effluent passes through the cathodic chamber and exits at the top continuously (Das,2010). They are quite simple to scale up than the double chambered fuel cells and thus have found extensive utilization and research interests lately ,(Liu ,2004).

1.3 Aim of project

This research is initiated to design a single chamber microbial fuel cell and to investigate the influences of the electrodes material, shape and size beside the distance between the electrodes on its performance.

2- Experimental Work

The electrochemical cell (reactor) constructed in this work is a single chamber MFC operates in batch mode as shown schematically in figure (1) blow.The cell consists of a (25x16x19) cm plastic container incorporating a heater to maintain a temperature of 30 C° which is the optimum temperature for the bacteria to be active. Air is supplied to the cathode through an external air pump at a rate of (7ml /min).Anode and cathode electrodes were connected with copper wires across an external resistance. Microbial growth at the anode was initiated by inoculation with wastewater from the Morjane Hospital wastewater treatment plant.

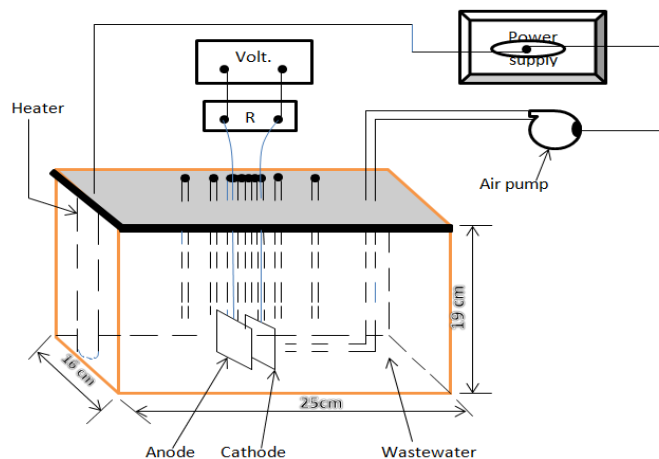


Figure 1.: Schematic representation of a microbial fuel cell

2.1- Wastewater sample

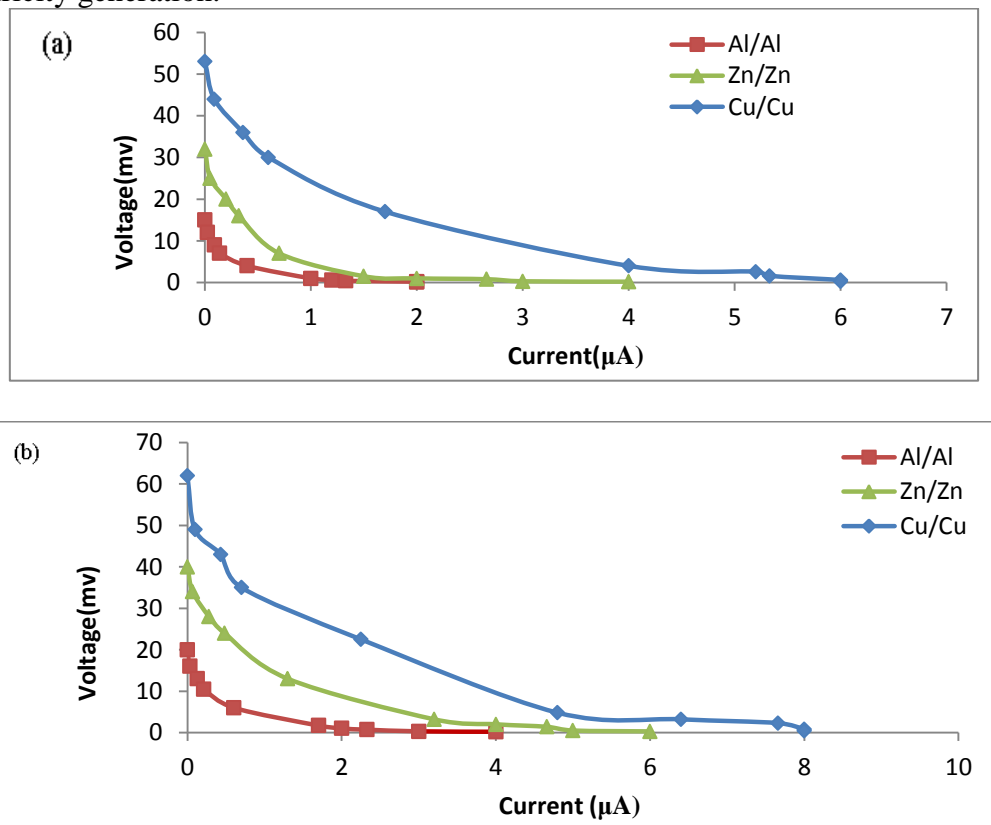
The Sample is taken from the sewer service water plant at the Morjane Hospital in Hilla city due to its high concentrated organic materials content. The following tests were carried out on the wastewater sample and the summarized results are tabulated in Table 1 below:

3-Results And Discussion

3.1- Influence of Electrode Material and Size on the Cell Performance

The Increasing conductivity of anode material, the minimizing contact resistance and the total travel distance of electrons within the anode helps in limiting the ohm losses.

Figure 2 shows the performance of the various combinations of circular anode / cathode electrodes; Al / Al, Cu / Cu and Zn / Zn in a MFC with the same cross sectional area for the anode and cathode equals to 3.14, 7.065 and 12.56 cm² at an operating temperature of T=30 C⁰ and a pH=7 for the wastewater. A 2 cm distance is maintained between the anode and cathode. The copper electrode shows higher OCV and cell voltage in comparison with the zinc and aluminum electrodes since copper has strong conductivity and weak electrical resistance and hence transfers high amounts of electrons. Furthermore, increasing the electrode size improves the OCV and cell voltages and hence indicating that the electrode size is a critical factor that affects power generation and internal resistance of the MFC due to the interaction between organic bacteria and inorganic electrode surface. Since, bacteria are solely responsible for generation of electrons and thus, electricity, providing large surface area for bacterial growth at anode this would then be a key parameter to enhance the electricity generation.



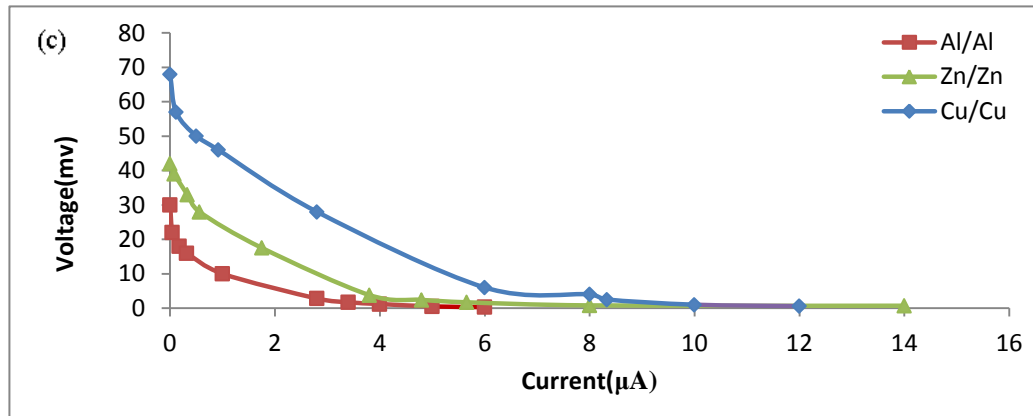


Figure 2: Voltage vs. Current of a microbial fuel cell with circular electrodes of anode cross sectional area is equal to cathode cross sectional area; (a) 3.14, (b) 7.065 and (c) 12.56 cm² at different electrodes materials with an operating temperature of T=30 C⁰ and pH=7 for the wastewater.

Figure 3 shows the performance of the various combinations of circular anode / cathode electrodes; Cu / Zn, Zn / Cu, Al / Cu, Cu / Al, Zn / Al and Al / Zn in a MFC with the same cross sectional area for the anode and cathode equals to 12.56 cm² at an operating temperature of T=30 C⁰ and a pH=7 for the wastewater. A 2 cm distance is maintained between the anode and cathode. The Zn / Cu electrode combination output the best performance in comparison to that of other combinations. The strong adsorption of zinc that could make large numbers of bacteria adheres to the surface of anode and showed a good performance. However, the lowest output voltage is produced by a MFC using copper as the anode since the toxicity of heavy metals decreases the activity of bacteria. Hence, copper is suitable cathode material of oxygen reduction which agrees with the published results ,Ashoka (2012).

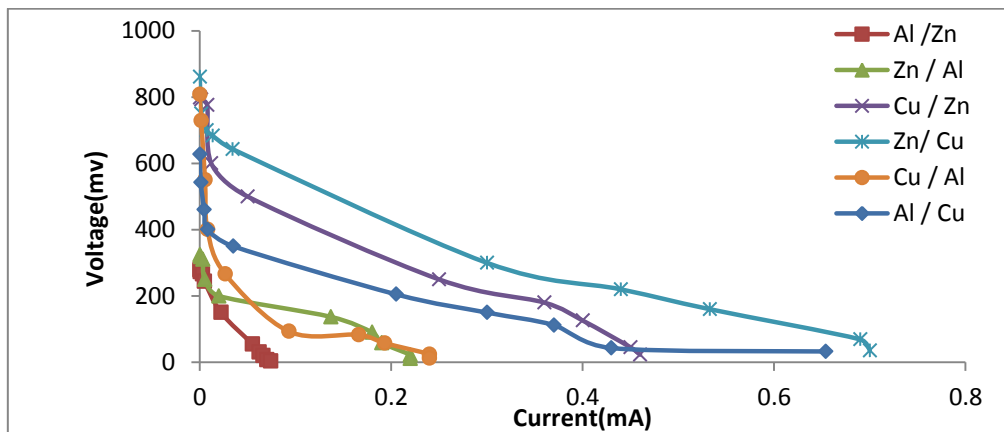


Figure 3: Voltage vs. Current of a microbial fuel cell with circular electrodes of anode cross sectional area is equal to cathode cross sectional area of 12.56 cm² at different electrodes materials with an operating temperature of T=30 C⁰ and pH=7 for the wastewater.

3.2 Influence of Electrode Shape on the Cell Performance

Figures 4 and 5 show the performance of the various combinations of anode / cathode electrodes in the shape of rectangle and square, respectively; Al / Al, Cu / Cu and Zn / Zn in a MFC with the same cross sectional area for the anode and cathode equals to 3.14, 7.065 and 12.56 cm² at an operating temperature of T=30 C⁰ and a pH=7 for the wastewater. A 2 cm distance is maintained between the anode and cathode. The copper electrode shows higher OCV and cell voltage in comparison with

their counter parts in the zinc and aluminum electrodes but their values are lower than those in Figure 3.1 with electrodes in circle shape because the current density is higher at the edges than it is at the center of the electrode. These results indicate that the shape of electrode is a major parameter that determining the power of an MFC, and the differences in the electrode shape lead to the differences in cell performance. A summarized comparison is given in Table 2 on page (10).

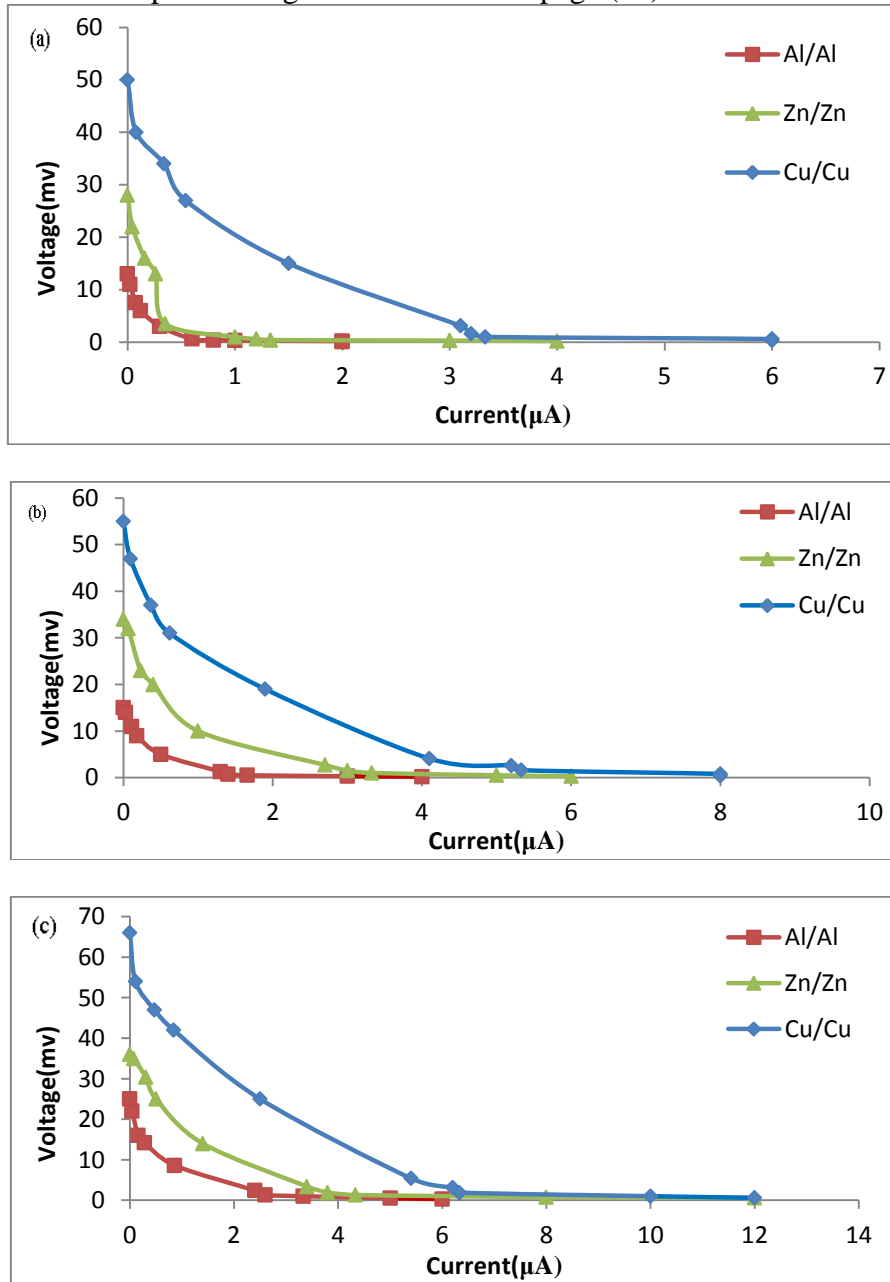


Figure 4: Voltage vs. Current of a microbial fuel cell with rectangular electrodes of anode cross sectional area is equal to cathode cross sectional area; (a) 3.14, (b) 7.065 and (c) 12.56 cm^2 at different electrodes materials with an operating temperature of $T=30\text{ C}^0$ and $\text{pH}=7$ for the wastewater.

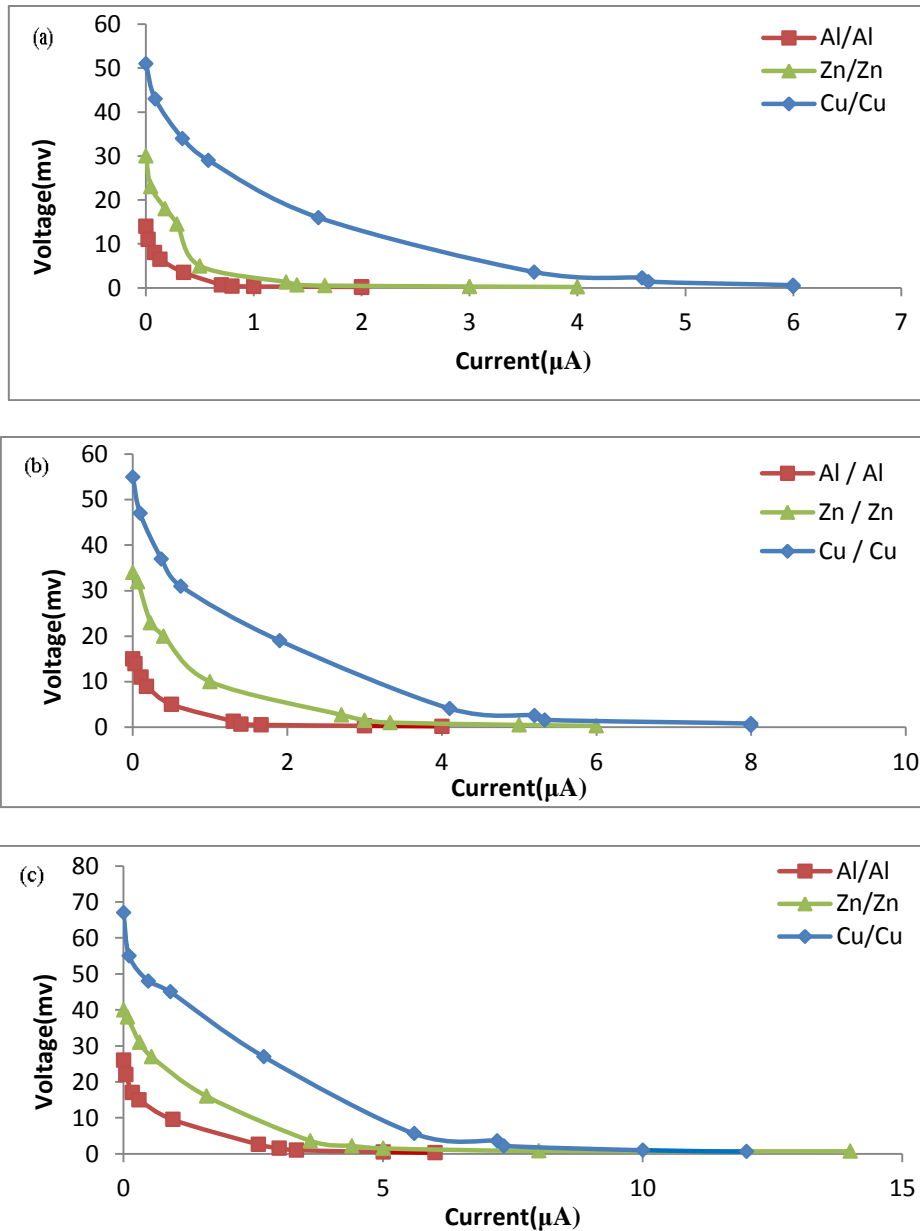


Figure 5: Voltage vs. Current of a microbial fuel cell with square electrodes of anode cross sectional area is equal to cathode cross sectional area; (a) 3.14, (b) 7.065 and (c) 12.56 cm² at different electrodes materials with an operating temperature of T=30 C⁰ and pH=7 for the wastewater.

Table 1: Influence of electrode material, size and shape on the performance of a microbial fuel cell.

Area (cm ²)	3.14			7.065			12.56		
	Anode / Cathode Cu/ Cu	Zn /Zn	Al/ Al	Cu/ Cu	Zn /Zn	Al/ Al	Cu/ Cu	Zn /Zn	Al/ Al
OCV of Circle electrodes (mv)	53	32	15	62	40	20	68	42	30
OCV of Rectangle electrodes (mv)	50	28	13	55	34	15	66	36	25
OCV of Square electrodes (mv)	51	30	14	58	35	16	67	40	26

3.3 Influence of Spacing between Electrodes on the Cell Performance

The aforementioned figures indicate that the copper / copper combination in circular shape with cross sectional area of 12.56 cm^2 is the best choice electrodes among the other combinations investigated in this study to construct the MFC.

The influence of the variations in distance between the anode and cathode electrodes in this MFC operates at an operating temperature of $T=30 \text{ C}^0$ and a $\text{pH}=7$ for the wastewater presented in Figure 6. Decreasing the distance between anode and cathode electrodes from 6 cm to 2 cm leads to the improve of the performance of the MFC because of the decrease in the internal resistance. Further reduction in distance to 0.5 cm shows a dramatic deterioration in the performance of the cell as a result of oxygen crossover through the cathode, and results in anode bacteria inhibited in current generation by the presence of dissolved oxygen, which agrees with the published results, (Logan ,2015).

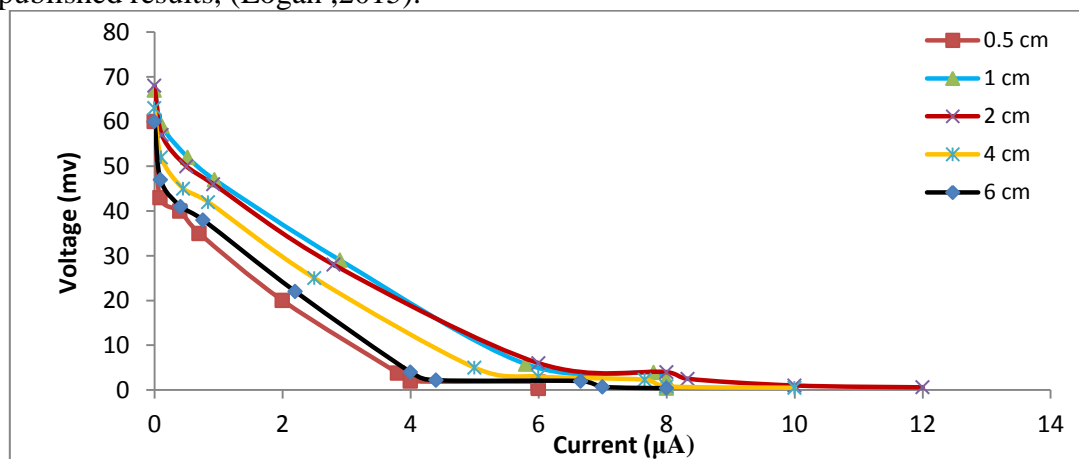


Figure 6: Voltage vs. Current of a microbial fuel cell with circular copper / copper electrodes of anode cross sectional area is equal to cathode cross sectional area of 12.56 cm^2 at an operating temperature of $T=30 \text{ C}^0$ and $\text{pH}=7$ for the wastewater.

3.4 Influence of Using Zn / Cu Electrodes on the Cell Performance

It is evident from Figure 7 that increasing the surface area of the cathode leads to improve the cell performance due to the increase in the ratio of cathode area to electrolyte volume and the aerobic biofilm layer projected to the oxygen, protons and electrons and consequently a high reduction rate due to the decrease in the ohmic resistance and hence a better interactions with microorganism and less mass transfer limitation. However, there is a slight reduction in the cell performance by using a circular cathode of a cross sectional area of 12.56 cm^2 in comparison to that of using a 7.065 cm^2 circular cathode at the activation and ohmic regions. This indicates that the chances for attachment of bacteria and generation of electricity in larger electrode surface areas might be limited by mass transport and by higher surface area as well as protons produced on the anode for example, they can't move fast enough at a low current to react with oxygen and electrons in the cathode chamber which leads to a high diffusion resistance (proton-transfer resistance). The reactive oxygen species resulting from fast oxygen reduction would exert incredibly high oxidative stresses on living organisms, resulting in accelerated ageing and death.

Increasing the area of the anode makes the cell producing more current as it can be noticed from Figures 7 and 8. The explanation of this is discussed earlier in section 1 above. While changing the shape of the anode has a little effect on the cell performance which is evident from Figures 7, 8. These results indicate that the area of the anode rather than its area influences the cell performance.

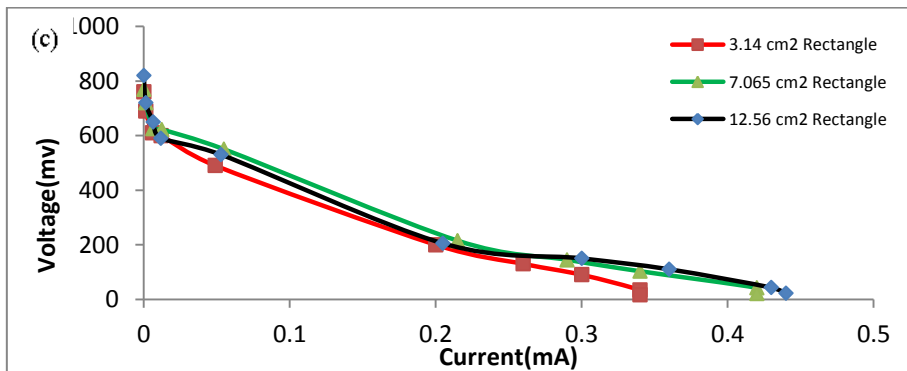
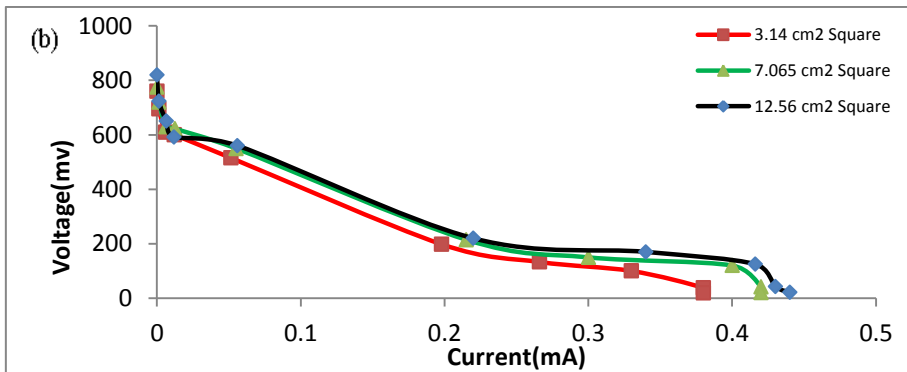
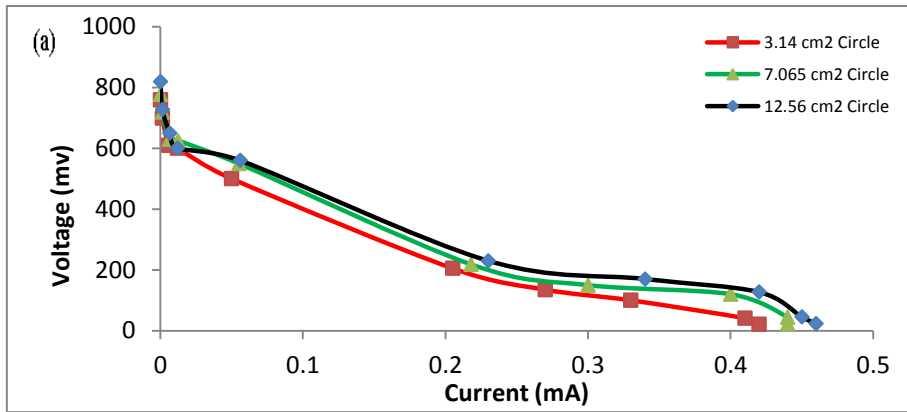
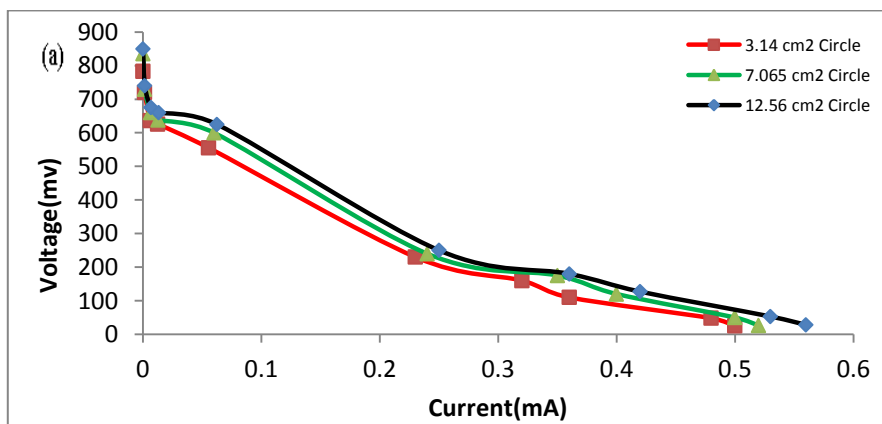


Figure 7 : Voltage vs. Current of a microbial fuel cell using a circular anode of cross section area (3.14 cm²) with; (a) circular, (b) square and (c) rectangular cathodes of three different areas at an operating temperature of T=30 C⁰ and pH=7 for the wastewater.



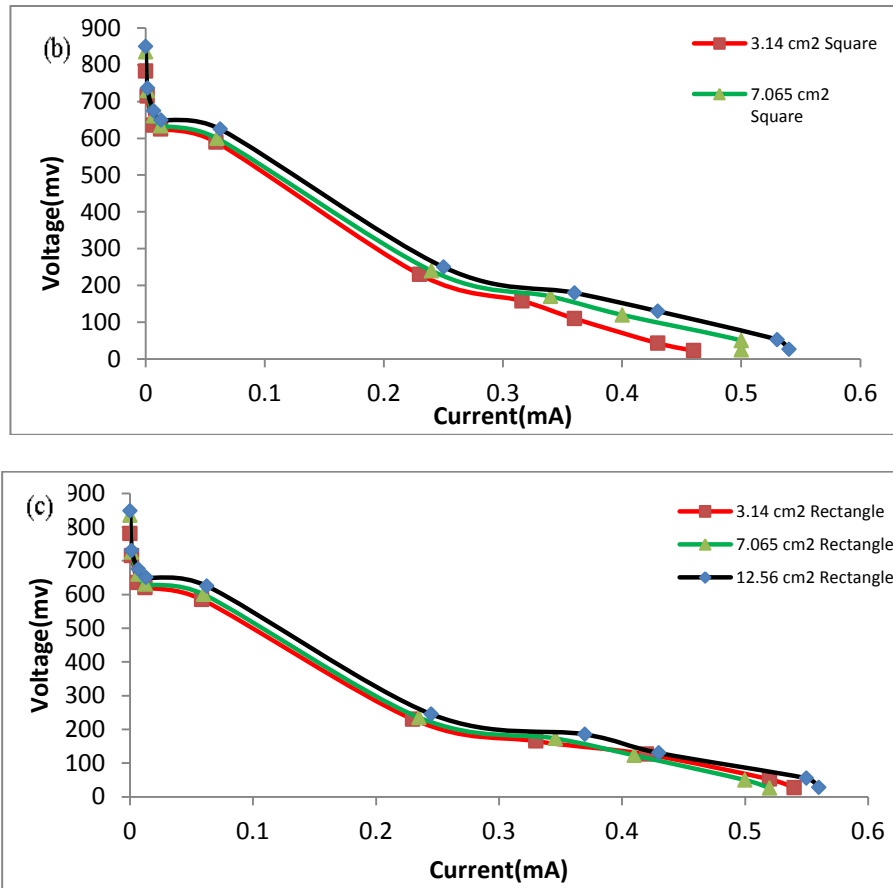


Figure 8 : Voltage vs. Current of a microbial fuel cell using a circular anode of cross section area (7.065 cm^2) with; (a) circular, (b) square and (c) rectangular cathodes of three different areas at an operating temperature of $T=30 \text{ C}^0$ and $\text{pH}=7$ for the wastewater.

4- Conclusions

The following conclusions can be drawn from the results obtained:

- 1- The Results indicate that the shape of electrode is a major parameter that determining the power of an MFC, and the differences in the electrode shape lead to the differences in cell performance. However, electrodes of circular shape show the best performance among other shapes investigated in this study. The Results signify that the area of the anode affects the cell performance more than its shape does.
- 2- The Zn / Cu electrode combination in circular shape with cross sectional area of 12.56 cm^2 output the best performance in comparison to that of the other combinations investigated in this study.
- 3- The lowest output voltage is produced by a MFC using copper as the anode since the toxicity of heavy metals decreases the activity of bacteria. Hence, copper is suitable cathode material of oxygen reduction
- 4- Decreasing the distance between anode and cathode electrodes lead to improve the performance of the MFC because of the decrease in the internal resistance but further reduction in distance showed a dramatic deterioration in the performance of the cell as a result of oxygen crossover through the cathode which, resulting in anode bacteria inhibited in current generation by the presence of dissolved oxygen.

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